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Logistic Analysis of the Effects of Shovel Trait on Carabelli's Trait in a Mongoloid Population

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ABSTRACT Mongoloid populations differ from Caucasoids by having a high prevalence of shovel trait and a low prevalence of Carabelli's trait. This study was conducted to investigate the effects of the shovel trait on Carabelli's trait in a Mongoloid population. The research design sought a population that resides in an isolated area and exhibits low admixture with neighboring populations. The Mongoloid group selected for study was the Bunun tribe of aborigines who inhabit an alpine area in Taiwan. The effects of sex and age on Carabelli's trait were controlled in this investigation, as was the association between tooth size and Carabelli's trait. Results show that males were more likely to have Carabelli's trait expressed on teeth than females. The buccolingual diameter of Carabelli's trait teeth was larger than that of teeth without the trait. After adjusting for sex, age, and tooth size, the existence of the shovel trait increased the likelihood of having Carabelli's trait by a factor of three, an effect that is significant.

Carabelli's trait molars and shovel trait incisors are dental features commonly used to differentiate Mongoloid from Caucasoid populations (Fig. 1). Carabelli's or shovel traits have been used as critical indicators for several decades, probably because the traits are simply observed in both living and skeletal materials, and can be used to show major ethnic differences in dentition (Lee and Goose, 1972). Two features of the Mongoloid dental complex are a high frequency of shovel incisors and a low frequency of Carabelli's trait molars (Dahlberg, 1951; Hanihara, 1968). It might have been hypothesized that shovel incisors repress the appearance of Carabelli's traits. However, the real effect of shovel traits on Carabelli's trait has been obscure.

Carabelli's traits are found on the lingual aspect of the mesiolingual cusp of the upper first molar teeth. The traits may take the form of a pit, fissure or cusp. Shovel traits are a combination of a concave lingual surface and elevated marginal ridges enclosing a central fossa in the upper right central incisor teeth. Few studies have examined the degree to which the existence of Carabelli's trait in the molar teeth is influenced by the existence of the shovel trait in the incisor teeth, although dental intertrait studies have been done before (Scott, 1977a,b, 1978, 1979; Doran, 1977; Mizoguchi, 1985; Motayam et al., 1985).

To reduce population differences in the manifestation of Carabelli's trait, we limited our investigation to the Bunun tribe of Taiwan aborigines. The Bunun aborigines live in isolated high mountain areas of central and southern Taiwan and have little admixture with non-Bunun peoples. These aborigi-

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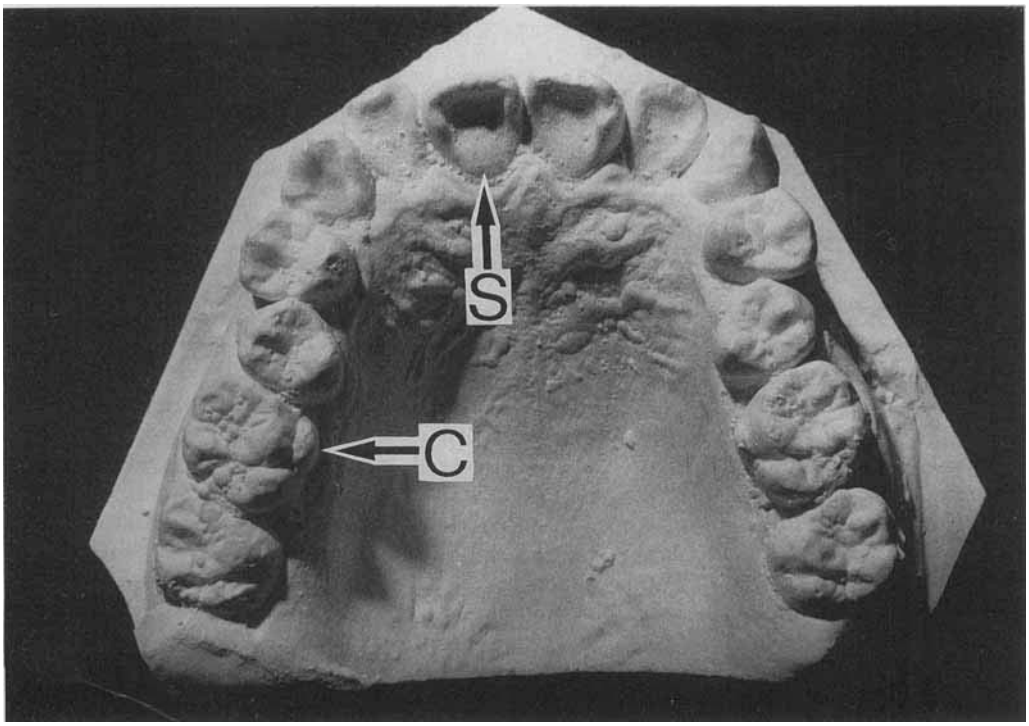

Fig. 1. Shovel trait (S) on upper right median incisor and cusp form of Carabelli's trait (C) on upper right first molar.

nes were already living in Taiwan when a large number of Chinese mainlanders migrated to Taiwan from Fukien and Kwangtung in the period after 1600 (Sung, 1980). Anthropological attributes of Taiwan aborigines indicate that they migrated from the south Asian mainland several thousand years ago and belong to the proto-Malays. This conclusion is based on their language, culture, and biology (Davidson, 1903; Utsurikawa et al., 1935; Chai, 1967; Chen, 1985; Liu, 1976; Turner, 1987; Manabe et al., 1991).

In addition to reducing the impact of population differences, other possible factors, such as sex and tooth size, which might affect the value for Carabelli's trait and might interfere with the influence of the shovel trait on Carabelli's trait, have to be considered. Although sex differences in the expression of Carabelli's trait have been reported (Goose and Lee, 1971; Kaul and Prakash, 1981; Kieser and Preston, 1981; Townsend and Brown, 1981; Noss et al., 1983), other authors have found no significant male–female differences in Carabelli's trait (Garn et al., 1966; Bailit and De Witt, 1968; Lombardi, 1975; Scott, 1980; Kieser, 1984). To control for potential differences caused by dimorphism, sex was considered as a possible confounding variable in this investigation.

Increased maxillary molar tooth size has been associated with the occurrence of Carabelli's trait (Keene, 1968; Lombardi, 1975). Tooth size is larger in Carabelli trait–positive than in Carabelli trait–negative molars (Reid et al., 1991). Because tooth size may be a confounding variable in our analysis of Carabelli's trait, we adjusted for tooth size. Our study explores the statistical effects of confounding variables, such as demography and tooth size, on Carabelli's trait in a Mongoloid population, the Bunun tribe

of Taiwan aborigines. This analysis also seeks to investigate the extent to which the shovel trait might affect Carabelli's trait after the removal of the effects of possible confounding factors.

MATERIALS AND METHODS

Data acquisition

Two hundred and forty-nine subjects participated in this study. To reduce the confounding effects of admixture on Carabelli's trait, subjects had to be members of the Bunun tribe of Taiwan aborigines. Tooth impressions were taken, and plaster models were made with rigid disposable trays and poured immediately in dental stone to prevent distortion. To reduce the possible discrepancy between deciduous and permanent dentitions, this study was restricted to permanent teeth (Kieser, 1984). In order to avoid the decrease in observable characteristics caused by dental caries and wear associated with advancing age, the age range was also limited to 12–15 years.

Morphological and metric inspections were made on 249 dental casts. Of this number, 233 could be appraised for upper right first molar and upper right central incisor measurements. Sixteen casts were excluded due to inability to measure tooth size and traits. There were no significant differences in demography between the participating group (233) and the nonparticipating group (16). In order to eliminate potential problems of asymmetry, analysis was limited to traits and measurements of the right side of the dentition (Keene, 1970; Saunders and Mayhall, 1982; Mayhall and Saunders, 1986). If a tooth was missing or could not be precisely measured due to the loss of measuring points through caries, restoration, or attrition, the corresponding contralateral tooth was not used as a substitute.

Some patterns of Carabelli's trait have been classified and contain (1) no evidence of Carabelli's trait—smooth surface with the absence of pits or fissures, (2) pits or fissures, (3) cusp without free tip, and (4) cusp with free tip (Kraus, 1951). Other forms of Carabelli's trait have been described, and even intermediate forms have been found (Dahlberg, 1963; Scott, 1980; Turner et al., 1991; Hanihara, 1992). The nonmetrical, categorical trait patterns have been dichotomized into two types, namely existence and nonexistence of Carabelli's traits. The presence or absence of Carabelli's trait was recorded for the upper right first molar, with the presence being coded when there was any manifestation of the trait, cusp, fissure, or pit.

Several classifications of the shovel trait have been suggested and include: (1) shovel—enamel rim distinct with an enclosed well developed fossa; (2) semishovel—enamel rim distinct but enclosed fossa shallow; (3) trace shovel—traces of enamel rim which cannot be classed as semishovel; and (4) no shovel—no perceptible trace of rim or fossa (Hrdlička, 1920). We used this system and the modified classifications (Dahlberg, 1956; Turner et al., 1991; Hanihara, 1992) to group upper right central incisor teeth. These categories were also dichotomized into groups, indicating existence and the nonexistence of shovel traits. The shovel trait–positive incisors were coded when rim or fossa could be observed.

A sliding electronic digital caliper wth 0.01 mm resolution was used to measure tooth size of upper right first molars of permanent teeth for each dental cast. Tooth size variables included mesiodistal and buccolingual diameters. The measurements of mesiodistal and buccolingual diameters followed Seipel (1946) and Moorrees et al. (1957). Mesiodistal diameter was measured as the greatest distance between the approximate surfaces of the crown with a sliding caliper parallel to the occlusal and vestibular surfaces of the crown. When a tooth was rotated or malposed in relation to the dental arch, the measurement was taken between the points on the approximate surface of the crown, where it was judged that normal contact should have occurred with neighboring teeth. Buccolingual diameter was measured as the greatest distance between the labial or buccal surface and the lingual surface of the tooth crown, measured with a sliding caliper held at right angles to the mesiodistal diameter of the tooth.

In order to decrease interobserver errors, mesiodistal and buccolingual crown dimensions of upper right first molars were measured directly on the cast by a single, well

trained examiner. A significant test–retest reliability ($r > 0.95$, $P < 0.001$) was found. Diameters were measured three times and the average value was recorded for each diameter. The morphological traits were classified independently by another examiner, whose incorrect percentage of trait classification was less than 3%.

Statistical analysis

Means and proportions for confounding variables were computed for the teeth with vs. without Carabelli's trait. Multivariate logistic regression was done with the SAS/STAT computer program (SAS Institute, 1989). We employed logistic regression, which has become the standard method of analysis in cases where the dependent outcome variable, such as presence or absence of Carabelli's trait, is dichotomous or discrete (Hosmer and Lemeshow, 1989). Because of a possible age effect on dental size and morphology, we controlled for age. In addition, we controlled for sex and tooth diameter to explore whether differences in the occurrence of Carabelli's traits on upper right first molars is influenced by the presence or absence of shovel traits on upper right central incisors. The logistic method enabled the comparison between presence and absence of the shovel trait for the differences in Carabelli's trait, while controlling for the effects of independent variables such as sex, age, and size of upper right first molars simultaneously. Tests for inference allowed a type I error rate of 5%. The odds risk and 95% confidence interval of odds risk were calculated. Odds risk is a measure that shovel trait is associated with Carabelli's trait. A significant odds risk was defined as an upper and lower 95% confidence limit not containing the value of one.

RESULTS

Male subjects comprised more than half (57.08%) of the sample. Of all participants, 48.07% had Carabelli's trait in the upper right first molars, and of male subjects, 58.45% had this trait. However, only 28.71% of female teeth had Carabelli's trait. The means and proportions of confounding variables of teeth with vs. without Carabelli's trait are shown in Table 1. The coefficients and the significance of independent variables in multivariate logistic regression are shown in Table 2. Significant differences were found between males and females for Carabelli's trait. A tooth exhibiting Carabelli's trait was significantly more likely to be in males than in females ($P < 0.001$). No age difference was observed between presence and absence of Carabelli's traits ($P > 0.05$).

TABLE 1. Confounding variables controlled in multivariate logistic regression

Variables	Carabelli's trait (N = 112)	No Carabelli's trait (N = 121)
Sex (% male)	74.36	40.12
Age (mean years)	13.36	13.50
MD URM1 (mean mm)[1]	10.57	10.47
BL URM1 (mean mm)[2]	11.37	11.15

[1] MD URM1: Mesiodistal diameter of upper right first molar.
[2] BL URM1: Buccolingual diameter of upper right first molar.

The possible confounding variables that were controlled for in the analysis are listed in Tables 1 and 2. Tooth size in the total sample is given by the mean ± standard deviation of mesiodistal and buccolingual diameters, which were 10.52 ± 0.52 mm and 11.26 ± 0.55 mm, respectively. The mean mesiodistal diameter of the tooth with Carabelli's trait was slightly larger than that of the tooth without Carabelli's trait, but it was not statistically significant after adjusting for sex, age, and buccolingual diameters ($P > 0.05$). On the other hand, after adjusting for the confounding variables, the mean buccolingual diameter of the tooth with Carabelli's trait was signficantly larger than that of the tooth without Carabelli's trait ($P < 0.05$).

Table 3 shows that the presence of the shovel trait in the upper right central incisors predicted the existence of Carabelli's trait in the upper right first molars three times more often than the absence of the shovel trait did (odds risk, 3.19; 95% confidence interval, 1.43–7.13; $P < 0.001$). Of all shovel trait teeth in the Bunun aborigines, 52.02% had Carabelli's trait teeth. Of all nonshovel trait teeth in the Bunun aborigines, only 25.71% had Carabelli's trait teeth.

TABLE 2. Estimates and standard errors in multivariate logistic regression: Carabelli's trait vs. no Carabelli's trait

Variables	Log odds		Statistical significance[3]
	Estimate	Standard error	
Sex	1.71	0.32	**
Age (years)	−0.29	0.17	NS
MD URM1 (mm)[1]	0.36	0.34	NS
BL URM1 (mm)[2]	0.57	0.26	*
Presence of shovel trait	1.16	0.41	**

[1]MD URM1: Mesiodistal diameter of upper right first molar.
[2]BL URM1: Buccolingual diameter of upper right first molar.
[3]Significant difference between with and without the Carabelli's trait measurements, $*P < 0.05$, $**P < 0.001$. NS: Not significant, $P > 0.05$.

TABLE 3. The effect of shovel trait on Carabelli's trait[1]

Groups	Carabelli's trait (N = 112)	No Carabelli's trait (N = 121)	Odds risk	95% confidence interval	*P*
Shovel	103	95	3.19	1.43–7.13	<0.001
No shovel	9	26			

[1]Statistic significance was determined by logistic regression controlling for the effects of sex, age, as well as both mesiodistal and buccolingual diameters of upper right first molars.

DISCUSSION

Nonmetric dental traits have been presumed to be quasicontinuous, or treated as continuous variables in many studies. Generally, the real trait expression intervals have been unequally classified into several categories, but equally continuous intervals have been assumed to apply. Further, examination of several types of dental trait classifications has found incorrect classifications occurred in 22%–56% of the cases (Kieser and Van Der Merwe, 1984). Finally, the criteria used to classify Carabelli's traits have been variably applied by different authors. For example, the "pit" feature has been given different values or degrees in different classifications. Some investigators have viewed "groove" and "cusp" as independent categories, but some have had categories for "cusp" in contact with "groove" or "cusp" with no contact. Another method, which assumes the existence of a threshold mechanism, has dichotomized nonmetric dental traits into present and absent groups (Hrdlička, 1920; Schuman and Brace, 1954; Carlsen, 1968; Lombardi, 1975; Liu, 1977; Smith et al., 1981; Manabe et al., 1992; Hanihara, 1992). Dichotomization reduces possible classification bias, but it also has other implications for dental traits.

This study found that Carabelli's trait is sexually dimorphic in Bunun aborigines. Similar findings have occurred elsewhere (Goose and Lee, 1971; Kaul and Prakash, 1981; Kieser and Preston, 1981; Townsend and Brown, 1981; Noss et al., 1983), but these are in contradiction with some other findings (Garn et al., 1966; Bailit and DeWitt, 1968; Lombardi, 1975; Scott, 1980; Kieser, 1984). It would appear difficult to conclude that sex differences exist in Carabelli's trait. However, it is worth noting that these previous studies are not completely comparable: Sample sizes vary, different methods of analysis have been employed, and the effects of confounding variables, such as mesiodistal and buccolingual diameter, have been rarely removed. These methodological differences may have led to contradictory findings. Certainly such analytic shortcomings influenced us to use multivariate methods in our own analysis, which then identified the existence of significant sexual dimorphism.

Among Bunun aborigines, after adjusting for sex and age, significant differences are present in buccolingual but not mesiodistal diameters. Such differences have been observed elsewhere (De Terra, 1905; Dahlberg, 1949; Reid et al., 1991). De Terra (1905) and later Dahlberg (1949) suggested that Carabelli's cusp is an adaptation that enlarged

the occlusal surface of the first molars in the buccolingual dimension as compensation for evolutionary reduction in the length (mesiodistal diameter) of the maxillary molar row. Another study reported that Carabelli's cusp is related to larger first molars overall, and not especially with an increase in the buccolingual diameter (Lombardi, 1975). The opinion from the evolutionary perspective has been that Carabelli's trait might be a primitive structure that tends to disappear with molar reduction in all hominoid evolutionary lines (Frisch, 1965; Hillson, 1986; Reid et al., 1991). A functional argument for the existence of Carabelli's trait has been the proposal that it may be a structure that resists excessive biomechanical stresses on the first molar (Mizoguchi, 1993). The theory that Carabelli's trait is a disappearing primitive structure is supported by the present study, which shows that smaller first molars tend to have fewer occurrences of Carabelli's traits. That Carabelli's trait serves a structural function needs to be tested with biomechanical experimentation.

Shovel trait occurs almost universally, and occurs particularly frequently in all Mongoloid groups, including Bunun aborigines, Chinese, Eskimos, and American Indians (Hrdlička, 1920; Dahlberg, 1951; Hanihara, 1968). Carabelli's trait is less commonly found in these populations (Lee and Goose, 1972). On the other hand, populations derived from Europe, such as American whites, have a low frequency of shovel trait and a high frequency of Carabelli's trait (Hrdlička, 1920; Lee and Goose, 1972; Mayhall et al., 1982). The literature shows that Caucasoid and Mongoloid population frequencies differ remarkably in the expression of Carabelli's trait on the upper right first molar and shovel trait on the upper right central incisor teeth (Koski and Hantala, 1952; Moorrees, 1957; Lee and Goose, 1972). As a consequence of this, shovel and Carabelli's traits have been regarded as dental markers of Mongoloid and Caucasoid ancestry. Understanding the real interaction between these two prominent dental markers is therefore of biological and anthropological interest.

Relatively little attention has been paid to the outcome of multivariate analyses of the effect of shovel trait on Carabelli's trait, though many papers have examined dental traits in Mongoloid populations (Nelson, 1938; Pedersen, 1949; Dahlberg, 1951; Moorrees, 1957; Mizoguchi, 1985; Townsend and Brown, 1981; Manabe et al., 1992). By confining our study to the Bunun aborigines only, we show that after adjustment, the presence of the shovel trait tends to increase the likelihood of Carabelli's trait by a factor of three. We have not found the expected negative impact of the shovel trait on Carabelli's trait after proper data adjustment, and we have clarified the interaction between these two dental markers. Given the positive association found in the present study, the reduction of Carabelli's traits is related to the reduction of shovel traits. Accordingly, from a hominoid evolutionary standpoint, an analogous developmental relationship between shovel and Carabelli's traits should be anticipated.

Other models which include genetic and environmental factors for the manifestation of Carabelli's trait have been reported (Goose and Lee, 1971; Lombardi, 1975; Townsend and Martin, 1992). It is likely that in addition to the environment, genes play a major role in the association between Carabelli's and shovel traits. Nevertheless, this assumption needs to be verified with family studies. Although the generalization of the intensity of the effect of shovel trait on Carabelli's trait seen in Bunun aborigines to other populations may be limited, this study promotes a method to investigate the influence of shovel trait on Carabelli's trait in other populations. In our opinion, such studies are needed.

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